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INTERNAL BROWNING OF THE YELLOW NEWTOWN APPLE.[1]

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HISTORY OF THE INVESTIGATIONS.

It has been recognized for a number of years that certain apples grown under particular climatic conditions and held in cold storage at temperatures around 32° F. are liable to develop a peculiar browning of the tissue of the fruit. This trouble has no external symptoms and can not be detected from the outside of the fruit. It was first brought to the attention of investigators of the Bureau of Plant Industry during the storage season of 1905–6. In the fall of 1905 a series of storage experiments with apples from various sections of California was begun under the direction of G. Harold Powell. On examination of the fruit in the spring of 1906, apples from the Pajaro Valley were found to be affected by this premature browning of the flesh, which was designated as internal browning.

[1] This bulletin reports the results of cooperative work between the Offices of Fruit-Disease Investigations and Horticultural and Pomological Investigations of the Bureau of Plant Industry. C. W. Mann, E. M. Harvey, and H. R. Kraybill, formerly members of the staff of one or the other of these offices, and C. F. Kinman and H. C. Diehl, now with the Office of Horticultural and Pomological Investigations, have materially assisted in experimental work in this investigation.

This browning of the interior of the fruit had been up to this time frequently confused with frost injury, due to low temperature of the storage rooms, with the result that claims for damages had been made and allowed. In Powell's storage experiments the records showed that the temperature of the fruit had not been below freezing at any time. The storage work was continued in 1906 and 1907 with similar results. The Red Pearmain (probably Pomme de Fer), White Pearmain, Yellow Bellflower, Missouri, and Yellow Newtown varieties from the Pajaro Valley were all more or less affected with this tissue browning, while apples from other localities in California stored under precisely the same conditions were sound. In the hope of determining the cause of this trouble and working out some method of preventing it, an investigation was begun by Powell and his associates. In this work various experiments were conducted on the relation of character of the soil, of delayed storage, and of the state of maturity at which the fruit was picked to the prevalence of this browning in the stored fruit.

At the request of the Bureau of Plant Industry a soil survey of the Pajaro Valley was made by Mackie, of the Bureau of Soils, United States Department of Agriculture.[2] No definite results as to the cause of the disease or methods for its control were obtained by Powell. The accumulated evidence was mostly negative in character and as such, of course, of value in the continued investigation of the trouble. Inasmuch as Powell did not publish his results and the work of Mackie dealt entirely with the soil survey, there is no account of these earlier investigations in the literature. In 1912, however, Stubenrauch, who worked with Powell in the early part of the investigation and was later in charge of the work, reported on the effect of different storage temperatures on the occurrence of browning.[3]

In experiments started in 1909 covering two years Yellow Newtown apples from various portions of the Pajaro Valley were stored at different temperatures and inspected several times during the storage season. The method of inspection was to remove boxes of fruit from each lot, cutting half the apples in each box crosswise immediately upon withdrawal. The rest of the box was allowed to remain at common market temperatures for 10 days and was then cut and inspected. A large quantity of fruit, some 300 or 400 boxes, cut and inspected during these two years, furnished a means of determining rather accurately the extent of browning and its progress dur-

[2] Mackie, W. W. Soil survey of the Pajaro Valley, Calif. *In* U. S. Dept. Agr., Bur. Soils, Field Operations, 1908, 10th Rpt., pp. 1331–1372, fig. 37. 1911.

[3] Stubenrauch, A. V. Fruit handling, precooling, and storage investigations. *In* Ice and Refrigeration, v. 42, No. 1, pp. 34–36. 1912.

ing the season. Stubenrauch found that the browning develops as the season advances, being much worse in the later withdrawals. It was also found that apples stored at 35° F. were in much better condition than those at 32° as regards browning. On May 9, the last inspection, 64.2 per cent of bad internal browning occurred in the apples stored at 32° and only 13.2 per cent in the fruit held at 35° F. By bad browning is meant internal browning that would affect the commercial value of the fruit. The results of these experiments were furnished to the cold-storage trade of California, and the higher storage temperatures were adopted for Yellow Newtown apples from the Pajaro Valley.

Little further discussion of internal browning is found in any published report. Powell[4] mentioned the occurrence of this trouble in apples in discussing storage problems before the American Warehousemen's Association, and there is mention of it in the reports of the Chief of the Bureau of Plant Industry[5] for the years 1910, 1917, 1918, and 1920. It was recently mentioned and certain findings reported by the California Agricultural Experiment Station.[6]

Many data on the earlier work on this trouble were obtained from the files of Field Investigations in Pomology, and some were furnished by William A. Taylor, formerly in charge of that office, and L. C. Corbett, now in charge of the Office of Horticultural and Pomological Investigations. C. W. Mann, who was associated with Stubenrauch in the later work on this problem, also furnished some information. As none of the present writers were connected with this work prior to 1917, it is probable that due credit may not be given the various men who have worked on this problem. In addition to those already mentioned, L. S. Tenny, H. J. Eustace, H. M. White, G. W. Hosford, H. J. Ramsey, A. W. McKay, and probably others have been connected with this work at some time, and the status of the problem when it was taken up by the present writers was due to their combined efforts.

The foregoing short historical sketch serves to introduce the present bulletin, in which an attempt is made to bring the account of this work up to date and to give some results of the further study for three years of this peculiar storage trouble of apples.

The Pajaro Valley apple district centers around Watsonville, about 100 miles south from San Francisco and near the coast. It is the most extensive apple-growing section of California, comprising

[4] Powell, G. Harold. [Internal browning of apples.] *In* Ice and Refrigeration, v. 36, No. 1, pp. 8–9. 1909.

[5] U. S. Department of Agriculture, Bureau of Plant Industry. Report of the Chief of the Bureau of Plant Industry, 1909–10, 1916–17, 1917–18, 1919–20. Washington, D. C., 1910–1920.

[6] Webber, Herbert J. Internal browning of the Newtown from the Pajaro Valley. *In* Calif. Agr. Exp. Sta. Rpt., 1919–20, p. 42. 1920.

in 1918 about 19,000 acres of orchards, practically all in bearing. The production for that year was approximately 4,500,000 packed boxes, or more than two-thirds of the apple crop of the State. The Yellow Newtown comprises more than half of the production of the district, while the Red Pearmain, another very susceptible variety, constitutes probably about one-thirtieth of the total output. A large part of the Yellow Newtown crop is marketed within the State, a portion is shipped to the central and eastern United States, and considerable quantities are exported. The bulk of the crop is packed in boxes and placed in cold storage, inasmuch as the Yellow Newtown is a long-keeping variety, capable of retaining its quality until late winter or early spring. It is evident from this description that, considering the total apple production of the United States, the percentage of the crop in danger of serious depreciation on account of internal browning is not large. Great financial losses, however, have resulted in the past to the apple growers of the Pajaro Valley from this deterioration of the stored fruit. It is therefore vitally important to the prosperity of this district that this trouble be investigated and methods worked out for its control.

So little has been written about this particular storage trouble that it has acquired no well-established name in commercial circles. It is sometimes referred to by the trade as "dry-rot," but that name is inappropriate, for the reason that the diseased tissue shows no noticeable drying out. The term "internal browning" was chosen because it suggests the appearance of the diseased tissue and also its location in the flesh of the apple. Since this internal browning develops only in low-temperature storage, the term "storage internal browning" would be more descriptive but is probably too long to come into general use.

DESCRIPTION OF INTERNAL BROWNING.

Careful investigations have established the fact that internal browning is not caused by a fungous or bacterial parasite. It is the result of certain abnormal physiological activities in the flesh of the apple classed in the general group of so-called physiological diseases. Internal browning does not appear in the fruit on the trees and does not develop if the apples are held at room temperature after picking. Regardless of some opinions to the contrary, it is not possible to predict from the external appearance of an apple whether or not internal browning will be found when the apple is cut open. In other words, internal browning does not manifest itself by any abnormal appearance of the skin of the fruit. It will be noted that this character is in contrast to the conditions obtaining in some other

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INTERNAL BROWNING OF YELLOW NEWTOWN APPLES.—I.

FIG. 1.—Cross section showing core lines. This condition of fruit is termed "sound."
FIG. 2.—Cross section showing bad internal browning within the core lines and only traces outside this region. This condition represents "trace tissue" and "bad core."

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INTERNAL BROWNING OF YELLOW NEWTOWN APPLES.—II.

FIG. 1.—Cross section showing extent and distribution of internal browning classed as "medium tissue" and "medium core." FIG. 2.—Cross section showing "bad tissue" and "trace core" browning.

physiological diseases, such as Jonathan spot, bitter-pit, and scald, in which discolored spots may appear in the skin of the fruit.

Plates I and II show various degrees of internal browning as it appears in cross sections of Yellow Newtown apples. It will be seen that internal browning may appear anywhere in the flesh of the apple, either immediately around the core or farther out toward the skin. Quite frequently internal browning appears only around the core, the outer fleshy portion of the apple remaining normal in appearance. On the other hand, though less frequently, only the outer flesh is involved. Usually when internal browning develops in the outer fleshy portion it is accompanied by browning around the core. There seems to be a tendency, however, for it to occur symmetrically as regards the morphology of the fruit. In very mild cases when an apple is cut crosswise only a small spot faintly tinged with brown may be seen in the angle between two adjacent seed cavities, the remainder of the cut surface appearing quite normal in color. In other cases faintly browned areas may appear around the core, accompanied by one or more discolored areas of various sizes and degrees of browning in the fleshy portion of the apple. Thus, all gradations from normal to badly browned core areas may be accompanied by equally varied conditions in the outer flesh of the fruit.

Frequently, in mild cases, a section through the widest diameter may show no internal browning, while further cutting, particularly toward the stem end, may reveal traces of this discoloration.

The fruit at picking time shows no visible indication of internal browning, and it is evident that the tendency to develop this trouble in storage is inherent in the fruit when it comes from the tree. Just what factors or conditions of the fruit determine this tendency the writers are not prepared to say, though interesting suggestions on this subject will be brought out later.

In presenting the results of these investigations it has seemed undesirable and unnecessary to include the long tables of figures and data that have accumulated from the work of each year. The data bearing on the most important phases of the subject have been condensed and tabulated for the purpose of giving the reader a clearer understanding of the results. Considerable information has been accumulated on certain chemical and physiological phases of apple storage as a result of investigations conducted for the purpose of learning something about the inherent differences between normal apples and apples subject to or showing internal browning. Unfortunately much of that work has contributed relatively little toward an understanding of the problem in hand, but the information gained is of value as an addition to our relatively meager knowledge of the physiology of cold-storage fruits.

EXPERIMENTAL WORK.

Previous to the time the present writers took up the work on internal browning considerable attention had been given to obtaining individual tree records from a number of orchards in the Pajaro Valley. This work has been continued and modified in some respects. Most of the work has been confined to orchards on the floor of the valley, but sufficient data have been obtained from trees growing at higher elevations, in the so-called mountain orchards, to establish a definite contrast in the susceptibility to internal browning of the two types of fruit. In addition fruit from a number of individual Yellow Newtown trees in the Yakima and Wenatchee Valleys of Washington and in Albemarle County in Virginia have been shipped to Watsonville and held in storage for comparison with the locally grown fruit. In this experimental work some attention has been given to the Red Pearmain variety, but for the most part the investigations have been confined to the Yellow Newtown, because of its greater commercial importance. Trees under observation have been marked by numbered indestructible metal tags. At picking time the desired quantity of fruit from each tree has been packed in commercial apple boxes and the boxes marked with the tree and orchard number. After picking, the fruit practically always has been placed in cold storage within 24 to 36 hours.

The fruit from the various orchards was picked each year at the time when the commercial harvesting was in progress in the particular orchards, and an attempt was made to gather apples from all parts of the tree, so that each box represented as nearly as possible a uniform sample of the crop on the tree. Usually, when only a record of internal browning was wanted, a single box was all that was taken from a tree. If it was desired to compare the effect of various storage temperatures on fruit from a certain tree or if larger quantities were wanted for experimental work, the required quantity was picked and carefully mixed before packing, in order to insure as far as possible a uniformity of fruit throughout the entire number of boxes.

During the progress of the investigations with which the present writers have been concerned, more or less continuous records have been obtained from a total of about 150 trees. During that time about 800 boxes of fruit have been carefully examined, and for the most part a record of the internal browning in each individual apple has been made.

The fruit has usually been left in storage until May or June, to allow the maximum development of internal browning. At the time of inspection the apples were examined as soon after removal from storage as possible, and in no case was the fruit taken from storage

allowed to stand more than a few hours before being inspected. With the exception of the crop of 1920, only half of each box was inspected immediately on removal from storage. The remaining half was then held for 10 days at room temperature and at the expiration of that time was inspected for the purpose of determining the increase in internal browning during that interval. This 10-day period after withdrawal from storage was chosen to represent the interval that might elapse in commercial marketing between the time of removal from storage and the consumption of the fruit by the ultimate purchaser. In the spring of 1921 the inspection at 10 days after removal from storage was omitted, the entire box being examined on withdrawal.

The method of recording internal browning requires some explanation. Mention has been made of the fact that internal browning often occurs only around the core and again, though much less frequently, only in the outer flesh of the apple. Thus, one may distinguish two types of the disease, and very often both types occur in the same apple. It has seemed desirable, therefore, to record the region in which internal browning has appeared in each apple examined, and also an approximation of the extent or intensity of the discoloration.

On examining cross sections of a Yellow Newtown apple (Pl. I, Fig. 1), a fine greenish line will be noted, which incloses an irregular, somewhat star-shaped area surrounding the seed cavities. For convenience in recording internal browning data, this area surrounding the seed cavities and bounded by this so-called core line has been termed the core region, and internal browning occurring in this region has been designated "core browning." Internal browning appearing outside the core line has been termed "tissue browning." The designations "core browning" and "tissue browning" are both open to criticism, but when their significance, as just explained, is kept in mind they will serve to characterize briefly the two types of internal browning which may occur. Obviously, also, the extent of tissue browning or of core browning varies in different apples, and it has been necessary to adopt some method of classifying each apple as to the extent of tissue or core browning it shows. Three grades—trace, medium, and bad—have been arbitrarily established, and so far as possible each grade has a commercial significance. The term "trace" indicates such a small extent of internal browning as would probably cause no depreciation in the commercial value of the fruit and includes those stages from the faintest discoloration, discernible only after considerable experience, to a more evident but still comparatively slight tinge of brown color. The term "medium" signifies a distinct browning, sufficient to detract somewhat from the commercial value of the fruit, while "bad" characterizes those stages

more pronounced than "medium" and sufficiently marked to lower the value of the fruit appreciably or even make it unsalable. The descriptions on page 5 accompanying Plates I and II will assist the reader in understanding the significance of the terms "trace," "medium," and "bad" as used in classifying the intensity of internal browning. It will be seen that these three classes grade from one to another with no sharp distinctions between successive classes, so that they serve only as a rough method of estimation.

The method of inspecting the fruit and recording the internal browning was as follows: Each apple was cut crosswise into approximately equal parts and the presence or absence of browning was noted. If no browning appeared the apple was recorded as sound regardless of any other imperfections that might be present. If internal browning was present, a record of its location, whether "core" or "tissue," and the extent, "trace," "medium," or "bad," was made. The total number of apples cut from each box was recorded and the records for each box and each tree were kept separately.

For the most part the fruit has been held in commercial cold-storage houses. In one of these houses the air circulation system was employed, air being cooled in a bunker room and circulated by fans through the storage rooms and back to the bunker room again. In the other plant each room was cooled by means of brine coils supported near the ceiling. In this case there was, of course, very little air movement within the storage rooms and no effort at ventilation. The concentration of carbon dioxid was sufficient at times to make it impossible to light a match. No direct comparison was made of the keeping quality of fruit stored in these two types of storage houses, but from general observations there appeared to be no noticeable difference.

RELATION OF INTERNAL BROWNING TO STORAGE CONDITIONS.

Previous to the year 1910 apples from the Pajaro Valley district were stored at temperatures around 32° F., approximating cold-storage temperatures used for apples throughout the United States. At that time, however, certain observations by Stubenrauch and other workers of the Bureau of Plant Industry led to the belief that internal browning developed to a much greater extent at temperatures near 32° than at 35° to 40° F. Consequently, after the year 1910 the commercial cold storages at Watsonville and other points in California, where the tendency of this fruit to develop internal browning in storage was known, raised the temperatures of their apple-storage rooms to 35° F. With the 1917–18 storage season, the temperature of storage was raised to 36° F. This is the temperature

still held in most of the apple storage houses of California, though some have recently been holding the rooms at 38° F.

Since the inauguration of temperatures of 36° F. or above in the holding of apples from this district little internal browning of commercial importance has occurred. This, in the light of the definite experimental data obtained during three seasons, has undoubtedly been due to the fact that the fruit has been held at higher temperatures during recent years.

In the autumn of 1918 one box of fruit was picked from each of 24 trees and shipped by express to Washington, D. C. There the fruit was at once placed in storage at 32° F. Exactly similar boxes from the same trees were held at Watsonville at 36° F. Although a possible error, due to different storage houses, time in transit, etc., is introduced, the fact that the lots of fruit were closely comparable when picked makes the data of much interest in connection with the temperature of storage which causes greatest development of internal browning. These data are presented in Table 1.

TABLE 1.—*Extent of the internal browning of Yellow Newtown apples stored at different temperatures in the season of 1918–19.*

[Fruit samples stored at 36° F. were so held at Watsonville, Calif., where grown; those stored at 32° F. were first shipped to Washington, D. C.

Temperature and time of sampling.	Number of trees.	Fruit sampled.		Comparison of results (per cent.)						
		Half boxes.	Number of apples cut.	Sound.	Tissue browning.			Core browning.		
					Trace.	Medium.	Bad.	Trace.	Medium.	Bad.
Held at 36° F.:										
At withdrawal..	24	24	1,429	32.0	9.2	5.1	5.2	15.5	18.3	27.9
Ten days later..	24	23	806	21.8	11.3	5.6	2.6	10.8	17.4	63.3
Held at 32° F.:										
At withdrawal..	24	24	1,161	28.6	10.1	10.9	20.1	25.1	18.2	20.2
Ten days later..	23	23	1,012	12.6	4.4	6.6	39.5	8.4	18.7	56.5

The summaries presented, representing samples of fruit from 24 different trees, indicate clearly that the apples shipped to Washington and there held at 32° developed much more internal browning than did those stored immediately at 36° F. at Watsonville. This is particularly true of the bad tissue browning, which, of course, is most serious from the commercial point of view. It was planned in further experiments to determine more accurately the effect of storing at different temperatures fruit treated in the same way and held under conditions exactly similar except for temperature.

During the autumn of 1919, 3 boxes of fruit were picked from each of 10 trees, care being used to obtain 3 boxes as nearly uniform as possible. These were forwarded by express to the University of California at Berkeley and stored in the experimental cold-storage plant of the pomology department. One box from each tree was stored at 32° F., another at 36°, and the third at 40°. Owing to an

accidental lowering of temperature, the apples in the room scheduled for 32° F. were badly frozen, so that no internal browning records could be obtained from this fruit. Although only a small amount of browning showed in either of the lots held at the higher temperatures, the summary, as given in Table 2, shows much more browning in the fruit held at 36° than in that stored at 40° F.

TABLE 2.—*Extent of the internal browning of Yellow Newtown apples stored at Berkeley, Calif., at different temperatures in the season of 1919–20.*

Temperature.	Number of apples cut.	Comparison of results (per cent).						
		Sound.	Tissue browning.			Core browning.		
			Trace.	Medium.	Bad.	Trace.	Medium.	Bad.
Held at 40° F.	756	87.3	1.6	0.13	0.13	5.4	3.4	2.1
Held at 36° F.	812	64.7	11.2	1.2	.1	13.4	8.9	7.0

TABLE 3.—*Extent of the internal browning of Yellow Newtown apples stored at different temperatures in the season of 1920–21.*

Tree and temperature.	Number of apples cut.	Comparison of results (per cent).						
		Sound.	Tissue browning.			Core browning.		
			Trace.	Medium.	Bad.	Trace.	Medium.	Bad.
Tree 1 (sprayed):								
At 31° F.	55	0	12.7	40.0	45.5	10.9	36.3	50.9
At 38° F.	62	46.8	0	0	0	40.3	8.1	4.8
Tree 10:								
At 31° F.	34	0	14.7	20.6	61.7	14.7	17.6	67.6
At 38° F.	43	23.3	0	0	0	39.5	23.3	14.0
Tree 69:								
At 31° F.	47	21	44.7	13.4	17.0	29.8	44.7	21.3
At 38° F.	51	43.2	9.8	0	0	45.1	3.9	7.8
Tree 134:								
At 31° F.	178	30.9	21.9	10.7	8.4	45.5	14.0	7.3
At 38° F.	82	85.5	0	0	0	7.3	4.9	2.4
Tree 142:								
At 31° F.	90	0	8.9	18.9	71.1	10.0	27.8	62.2
At 38° F.	66	40.9	44.0	0	0	45.5	4.5	0
Tree 143:								
At 31° F.	56	3.6	21.4	8.9	53.6	17.9	23.2	53.6
At 38° F.	63	33.3	22.2	4.8	0	50.8	11.1	1.6
Tree 260:								
At 31° F.	86	0	12.8	27.9	55.8	7.0	17.5	76.8
At 38° F.	63	1.6	46.1	17.5	3.2	15.9	34.9	47.6
Tree 262:								
At 31° F.	67	0	4.5	22.4	73.2	1.5	9.0	23.9
At 38° F.	77	18.2	13.0	0	0	44.2	11.7	13.0
Tree 280:								
At 31° F.	123	17.9	35.8	8.9	0.8	52.8	20.3	7.3
At 38° F.	95	91.7	1.1	0	0	4.2	3.2	1.1
Tree J 247:								
At 31° F.	48	62.5	14.6	0	0	37.5	0	0
At 38° F.	68	95.6	0	0	0	2.9	1.5	0
Tree J 248:								
At 31° F.	64	28.1	37.5	1.6	0	62.5	9.4	0
At 38° F.	78	93.7	0	0	0	5.1	0	1.3
Tree 33:								
At 31° F.	52	1.9	30.8	30.8	21.2	23.1	34.6	38.5
At 38° F.	68	36.8	2.9	0	0	32.4	13.2	17.7
Summary:								
At 31° F.	900	14.3	21.9	16.4	30.2	29.7	20.0	30.1
At 38° F.	816	54.4	11.0	1.7	0.25	25.6	9.2	8.6

During the fall of 1920 duplicate boxes of fruit were picked from each of 12 trees. One box from each tree was stored at 38° F. and the other at a temperature that fluctuated somewhat but averaged about 31°. At the time the fruit was stored the temperature was somewhat below 31°, but was raised until by the time the inspection was made in March it was about 33° F. The average represents about the temperature at which apples are usually held in cold storage at points outside of California. Table 3 gives in detail for each tree the percentage of browning of fruit in the 38° storage and that at 31° F.

From an examination of the data presented in Table 3 it is at once apparent that whereas very bad internal browning had developed in fruit held at 31° there was very little in that held at 38° F. As was noted in describing the browning, fruit listed as "trace," whether tissue or core, shows so little discoloration that it is practically negligible from the commercial viewpoint. Medium and bad core browning represent discoloration about the core that detracts from the value of the fruit. The medium and bad tissue browning represent marked discoloration throughout the flesh of the fruit outside the core line and may render the fruit practically unsalable. Of the fruit held at 31° F. more than 46 per cent was in these last two classes, while less than 2 per cent of that held at 38° showed this degree of browning. It is obvious from the data presented that if the commercial fruit from the Pajaro Valley stored during the season of 1920–21 had been kept at the 30° to 32° F. temperatures used for apples in most sections of the country the loss would have been very severe. Fortunately, most of it was held at 36° to 38° F., so that the discoloration was not sufficient to affect seriously the marketability of the fruit.

Of special interest to the commercial industry is the question of the development of the internal browning upon the removal of the fruit from cold storage. A certain period must necessarily elapse between the time of removal of the fruit from cold storage and its ultimate consumption. In practically all these investigations an inspection was made at the time the fruit was withdrawn from storage and another after the fruit had remained out of storage for 10 days. As has been mentioned, half of each box was cut at the first inspection and the remaining half at the second, so the results are very closely comparable. A summary of the data is presented in Table 4.

TABLE 4.—*Progress of the development of internal browning in Yellow Newtown apples after removal from cold storage in three different seasons.*

Storage season and orchard.	Time of inspection.	Apples cut.	Bad tissue browning.	Bad core browning.	Temperature of storage.
		Half boxes.	*Per cent.*	*Per cent.*	°*F.*
Season of 1915–16:					
Rodgers Bros. orchard	At withdrawal	51	10.5	13.1	35
	10 days later	51	15.5	19.9	
Floyd Rodgers orchard	At withdrawal	68	10.5	12.8	35
	10 days later	68	22.9	29.7	
Season of 1916–17:					
Rodgers Bros. orchard	At withdrawal	61	19.3	23.7	35
	10 days later	61	29.0	40.4	
Floyd Rodgers orchard	At withdrawal	52	29.8	30.2	35
	10 days later	52	34.7	41.7	
Season of 1918–19:					
Rodgers Bros. orchard	At withdrawal	311	2.6	6.1	36
	10 days later	311	2.4	17.9	
Floyd Rodgers orchard	At withdrawal	150	3.1	22.3	36
	10 days later	150	3.6	46.5	
Rodgers Bros. orchard	At withdrawal	19	14.3	11.0	32
	10 days later	19	16.6	17.7	

It is apparent from the data in Table 4 that there is a marked increase in the extent of internal browning in the 10 days under market conditions after the fruit has been removed from cold storage. Large quantities of fruit were used in the storage experiments, so that the averages presented correspond closely to what may be expected under commercial conditions. Only the data for bad tissue and bad core browning have been presented, as these conditions are most important in affecting the sale of the fruit.

During the seasons of 1915–16 and 1916–17 considerable browning developed, and the increase after removal from storage was very marked. In 1917–18 so little browning developed that the data are not included. In 1918–19 the tissue browning was very light and the increase following removal from storage was less marked, although core browning was much more in evidence at the second inspection. From the data presented it is obvious that if browning is present in the fruit while in cold storage it may be expected that this will be much worse by the time the fruit reaches the consumer.

RELATION OF INTERNAL BROWNING TO ORCHARD CONDITIONS.

Certain peculiar characteristics of the occurrence of internal browning early directed the attention of investigators to the importance of a study of orchard conditions in relation to this trouble. The fact that the browning occurs much more commonly in apples from the Pajaro Valley than in fruit grown in other parts of the United States has directed attention to a study of various factors of orchard management in that district in relation to their effect on browning. These studies include observations on the compara-

tive tendency to internal browning of apples from various parts of the district, the effect of thoroughness of orchard tillage and of various commercial fertilizers and barnyard manure on this tendency, a study of individual trees to determine whether the production of apples which brown in storage is a tree characteristic, and finally a detailed study of tree characteristics, such as quantity and condition of foliage, size of crop, and the size of individual apples on the trees. These have been augmented by chemical and physiological studies of fruits remaining sound as compared to those becoming browned in storage.

The Pajaro Valley is almost surrounded by mountains or hills which are very low toward the sea, some 4 to 8 miles distant from the apple plantings, and rise to considerable heights on all other sides of the valley. Most of the orchards are on the floor of the main valley, though a number extend up some distance on the surrounding hills and into smaller valleys which are cut off from the ocean by ranges of hills much higher than those bordering the Pajaro Valley proper.

As in California generally, the year is divided into two seasons, the rainy and the dry. The rainy season extends from October to April, inclusive, and during that time there is an average precipitation of about 25 inches. Throughout the remainder of the year showers are rare and of practically no importance. The winter weather is mild, and comparatively little frost occurs.

In the summer and early fall the valley is subject to low-velocity trade winds from the ocean. They begin to blow between 10 o'clock and noon and continue until late afternoon. As a result, the evenings are cool or even chilly. Frequently the winds bring in fogs, which begin to cover the valley about 4 o'clock in the afternoon and remain until 9 or 10 o'clock the following morning. These fogs are of two types, high and low. The high fogs are at an elevation of several hundred feet, while the low fogs lie close to the ground, enveloping the trees, and sometimes drenching the foliage during the night and early morning. The points to be noted in this connection are the cutting off of the direct sunshine and the consequent lowered temperature and increased humidity during the growing period. This foggy weather is interspersed with clear periods of 2 to 10 days. The daily fluctuation of temperatures is between 50° and 65° F. during the foggy weather and between 65° and 80° F. during the clear period. Temperatures above 90° F. are rare, occurring not oftener than once or twice during the summer and early fall. These fogs are relatively much more prevalent over the floor of the valley proper, which is open to the sea, than over the higher foothill regions or over the more protected interior-valley orchards. These

foothill and inland orchards have relatively a somewhat higher temperature, more sunshine, and lower humidity.

For several years fruit has been gathered from orchards located well up on the hills, above the fog belt, and also from several different orchards down on the floor of the valley. The fruit from these different orchards has been handled in the same way, stored under similar conditions, and inspected in the spring to determine the distribution of orchards producing fruit which tends to brown internally during storage. This fruit has been compared with Yellow Newtown apples from Virginia and from the Yakima and Wenatchee districts of Washington.

Some internal browning has been found to occur in Yellow Newtown apples from all these fruit-growing sections as well as from all parts of the Pajaro Valley apple district. From the sections outside the Pajaro district, however, and in the hill orchards in that district, internal browning has been found only to such a small extent as to be of little importance in a commercial way. Only in fruit from the orchards on the floor of the valley, in the summer fog belt and growing in soil of very high fertility, has this trouble been particularly serious. These observations are based on the inspection of hundreds of boxes of fruit extending over several years. The detailed records of these inspections are much too voluminous to be included in this bulletin.

RELATION OF INTERNAL BROWNING TO SOIL FERTILITY AND FERTILIZERS.

In order to determine whether internal browning is related to any soil deficiency either of an organic or of an inorganic constituent, a series of fertilizer plats was laid out in 1917 and initial applications were made. Three plats were established, trees outside the plats receiving no fertilizer treatment serving as a check. Each plat contained 15 trees.

Plat 1, known as the nitrogen plat, received 10 pounds of ammonium sulphate per tree in 1917. As the trees were very large and no appreciable response could be detected from this treatment, the quantity was increased to 20 pounds in 1918. In 1919 sodium nitrate was used instead of the ammonium sulphate, and in 1920 20 pounds of ammonium sulphate were again added.

Plat 2, the manure plat, was started in the spring of 1917. Soil was removed from around the trees in an area equal to about the spread of the branches, and about a ton of barnyard manure was applied at the base of each tree. In addition, 20 pounds of steamed bone meal, containing about 20 per cent of phosphoric acid and 4 per cent of nitrogen, were added for each tree. Thus, each tree in the plat was very heavily fertilized with phosphoric acid, nitrogen, and organic matter, while considerable potash was available in the manure. No subsequent applications of fertilizer were made.

Plat 3, the phosphorus plat, received 20 pounds of superphosphate per tree on April 3, 1918. In 1919 10 pounds of superphosphate and 10 pounds of steamed bone meal were added. In 1920 6 pounds of steamed bone meal were added for each tree.

All fertilizers were applied in the spring before cultivation was completed, and were thoroughly worked into the soil.

GROSS EFFECT OF FERTILIZERS.

During the first two seasons little influence of the fertilizer could be detected in any of the plats. During 1919, however, it was evident that the foliage of the trees of the nitrogen plat was better than that of the surrounding trees, the leaves being larger and greener in appearance. In 1920, a year of very short crops for the orchard as a whole, trees in this plat produced more nearly a full crop.

It has been impossible to determine any influence of the phosphorus fertilizer in plat 3. Foliage, crop, and fruit were about as in the untreated trees in the orchard.

Trees in the manure plat were no better in appearance than surrounding untreated trees. The foliage was very poor, and the set of fruit on the trees in the years when the orchard as a whole bore a light crop was even below that of the surrounding trees.

INFLUENCE OF FERTILIZERS ON THE INTERNAL BROWNING OF THE FRUIT.

Table 5 gives the average percentages of browning in fruit from each fertilizer plat during the seasons of 1918–19 and 1920–21, during which browning has occurred to an appreciable extent, since the treatment was initiated.

TABLE 5.—*Summary of the influence of fertilizers upon the internal browning of Yellow Newtown apples in two different seasons.*

Season, plat, and treatment.	Number of trees.	Number of apples cut.	Comparison of results (per cent).						
			Sound.	Tissue browning.			Core browning.		
				Trace.	Medium.	Bad.	Trace.	Medium.	Bad.
Season of 1918–19; storage temperature, 36° F.:									
Plat 1, nitrogen	15	982	48.7	10.2	10.2	10.7	17.6	13.2	9.2
Plat 2, manure	15	1,004	11.4	24.4	16.6	8.3	16.9	29.9	33.5
Plat 3, phosphorus	15	945	27.4	8.0	3.1	1.9	19.2	22.5	24.7
Plat 4, check	9	817	23.9	15.2	8.3	5.9	16.5	25.1	26.3
Season of 1920–21; storage temperature, 31° to 32° F.:									
Plat 1, nitrogen	15	1,560	18.4	24.4	16.3	17.8	38.2	21.0	18.6
Plat 2, manure	15	1,571	8.7	25.1	14.1	25.1	29.4	27.0	30.9
Plat 3, phosphorus	15	1,543	9.0	28.0	22.9	13.9	33.4	37.5	20.2
Plat 4, check	9	967	7.1	31.9	13.5	10.4	32.0	34.1	26.0

A study of the data presented in Table 5 shows that there was no clear-cut response to the fertilizer treatment as evidenced in the fruit. Certain observations on the effect of these fertilizers are worthy of note. Each year there was a markedly higher percentage of sound fruit in the nitrogen plat than in any other. The percentage of bad tissue browning in the fruit from trees of this plat, however, was also highest during the first season and second only to that of the manure plat the second year. In checking over the individual tree records on this plat, the remarkable fact has developed that during each year the trees producing the highest percentage of fruit which became badly browned were in this nitrogen plat. The foliage and general appearance of these trees have been the best of those under test, and generally the fruit has been either exceptionally good or exceptionally bad in its tendency to brown internally. These phenomena will be considered further under the subject of crop yield and browning.

The phosphate and check plats have had only a moderate percentage of browning. There has been little sound fruit, however. Generally, the fruit has shown traces of browning, with little entirely sound and little particularly bad.

On the whole, there has been a higher average percentage of browning in the manure plat than in any other. The percentage of sound fruit has been low, and there has been an abundance of bad browning, particularly bad core browning, in the fruit.

In general, it may be said that the results have been negative so far as causing or preventing browning through fertilizers is concerned. The points brought out are of interest, however, particularly when viewed in the light of the relationship of browning to yield, discussed later in this bulletin.

RELATION OF INTERNAL BROWNING TO THE INDIVIDUAL TREE.

During the early investigations of this trouble it was apparent that there is oftentimes a very distinct variation in the extent of browning which appears during storage in fruit from different trees, even when such trees are growing adjacent to each other. Consequently, for the past six years fruit from the different trees in the orchards under observation has been kept separate, and the average performance records of a large number of trees over a period of several years have been obtained. Only the summaries of these records will be presented here.

It was in the minds of the investigators during the first years in which these records were made that the tendency of the fruit to brown in storage is a tree characteristic and that certain trees tended to produce fruit year after year that was inherently sound, while other trees regularly produced fruit that tended to become

badly browned after a season in cold storage. After the records of the work of three seasons were available, however, it was evident that this condition does not hold true. In certain instances, trees have produced sound fruit a number of years in succession, while others have produced fruit with a tendency to bad browning in successive years. But this condition by no means holds generally, and very often a tree which produces sound fruit one year will produce fruit tending to brown very badly the next year. In other words, it is impossible to predict what a tree will do, basing the prediction on its previous performance record.

DEFOLIATION AND GIRDLING EXPERIMENTS.

In order to obtain evidence, if possible, upon the internal condition of nutrition in the trees that are associated with the occurrence of browning, it was planned during the summer of 1919 to vary the nutritive conditions in different parts of the same tree and to determine the effect of these treatments on the development of internal browning.

Six trees were selected for special treatment, three of which during the preceding year had produced fruit that tended to brown badly and three of which had produced fruit that remained sound. All trees were bearing heavy crops of fruit.

Branches as nearly uniform as possible and ranging from 1 to 2½ inches in diameter were selected. On each tree certain branches were girdled by removing a ring of bark one-eighth to one-fourth inch wide around the branch near its base. Other adjacent and similar branches were treated by removing about half the leaf area from the branches. Partially defoliated branches in all cases were well loaded with fruit, while in the cases of girdled branches the number of apples on each branch was reduced by thinning until no two fruits were closer together than 5 inches. All of this work was done on June 26, 1919, when the fruit was about three-fourths of an inch to 1 inch in diameter. Adjacent branches receiving no treatment served as checks to the treated ones.

Fruit on the girdled branches was very large at the time of picking, which was in the first week of October. It was yellow tinged and well ripened and had a tendency to water core. The fruit on branches that were partially defoliated, on the other hand, was small and green in appearance at the time of picking. Normal fruit on the same trees was intermediate in degree of apparent maturity and in size. Chemical analyses made at the time of picking and again at the time of the inspection of the fruit upon its removal from storage in May, 1920, showed that the fruit from girdled limbs was markedly higher in both total sugar and in

titrable acid than normal fruit from the same trees, while fruit from the defoliated branches was lower in both sugar and acid. The very marked differences in size and appearance of the fruit from girdled and from defoliated branches, as well as the distinctive variation in sugar and acid in fruit following these two methods of treatment, together with the records on internal browning of the fruit, make this experiment of considerable interest. The data are given in Table 6.

TABLE 6.—*Effect of girdling and of defoliating branches upon the development of internal browning and upon the acid and sugar content of fruit during the growing season of 1919.*

Tree and treatment of branches.	Number of apples cut.	Comparison of results (per cent).								
		Sound.	Tissue browning.			Core browning.			Titratible acid (as malic).		Total sugar, June, 1920.
			Trace.	Medium.	Bad.	Trace.	Medium.	Bad.	Oct., 1919.	June, 1920.	
Tree 3 (sprayed):											
Girdled	125	52.0	19.2	0	0	16.8	12.0	16.8	0.526	0.340	10.60
Normal	92	71.7	0	0	0	10.9	7.6	9.8	.496	.311	.....
Defoliated	172	96.0	0	0	0	23.0	.6	1.2	.447	.300	9.50
Tree 44:											
Girdled	268	31.3	17.9	2.2	0	21.3	16.1	26.9	.562	.376	10.76
Normal	180	77.8	4.4	0	0	11.7	1.1	6.1	.488	.358	9.66
Defoliated	298	94.4	.3	0	0	3.0	1.3	1.0	.469	.321	9.67
Tree 134:											
Girdled	201	19.9	29.8	6.0	2.5	13.9	15.4	41.8	.597	.403	11.38
Normal	266	67.0	0	0	0	12.4	7.9	12.8	.592	.401	10.62
Defoliated	253	74.8	2.4	0	.4	6.7	6.3	11.9	.551	.370	10.32
Tree 135:											
Girdled	130	29.2	46.9	10.9	3.8	19.2	17.7	14.6	.596	.356	10.76
Normal	306	75.2	15.7	4.2	.7	4.2	2.3	.7	.474	.337	9.83
Defoliated	164	97.6	2.4	0	0	1.2	0	0	.445	.248	9.59
Tree 136:											
Girdled	337	31.2	42.2	13.9	2.4	20.2	10.7	20.2	.585	.310	10.02
Normal	293	68.6	19.1	1.7	1.0	8.9	4.1	3.8	.536	.315	9.04
Defoliated	350	90.9	4.3	.3	0	4.3	1.1	.9	.553	.298	9.18
Tree 151:											
Girdled	192	58.4	26.0	6.8	.5	13.0	6.2	5.7	.546	.353	9.95
Normal	191	91.7	0	0	0	4.7	2.6	1.0	.538	.295	9.28
Summary:											
Girdled	1,253	35.4	30.7	8.0	1.5	17.9	12.8	21.9	.569	.356	10.58
Normal	1,328	74.5	8.4	1.4	.4	8.4	4.1	5.2	.521	.336	9.69
Defoliated	1,247	89.3	2.1	.1	.1	3.8	2.0	3.0	.493	.307	9.65

The data presented in Table 6 reveal at once that there was a very wide variation in the extent of browning occurring in fruit from branches receiving the various treatments. Invariably the fruit from girdled branches showed the highest percentage of apples affected with internal browning and the lowest percentage of sound fruit. Not only is this the average condition, but it also holds for the fruit from each tree taken individually. The normal fruit, from untreated branches, was much better in keeping quality than that from the girdled limbs, while fruit from branches having about half the leaves removed was markedly better than the normal fruit. Thus, in fruit from the same tree the apples supplied with the

greatest quantity of carbohydrate, as obtained by girdling the branches and thinning the fruit, tended most to browning.

When the analyses presented in Table 6 are studied, however, it is evident that there is a considerable variation in the acid and sugar content of the fruit from different trees, without a corresponding variation in the extent of browning that developed. For example, even the fruit from defoliated branches from tree No. 134 was higher in sugar content than fruit from girdled or normal branches from either tree No. 151 or tree No. 136. Within the individual tree, the apples from the girdled branches, running high in sugar and acid as compared to normal for the tree, have shown a marked tendency toward browning, but there is no evidence to indicate that trees that normally produce fruit with high sugar content also produce fruit with a marked tendency toward browning.

The analyses presented in Table 6, considered in connection with other unpublished data on apple analyses, indicate that there may be a wide variation in the chemical composition of the fruit from different trees in an orchard and from year to year from the same tree. The results obtained by girdling and defoliating indicate that the browning of the fruit in storage is associated with conditions that produce high sugar and acid content for that tree, but not that trees normally producing fruit of high sugar and high acid content tend to produce fruit with a greater tendency to browning than trees that normally produce fruit of low sugar content. In fact, the evidence available at the present time indicates that the greatest tendency to browning occurs in trees which normally produce fruit of rather low sugar content.

From a consideration of the foregoing data, it appears to be established that internal browning of apples in storage results from certain conditions within the tree. These conditions are not fixed, in the sense of being constant or hereditary, for a tree may produce fruit that browns badly one year and be almost free from browning the year following. Rather than being a tree characteristic, browning of the fruit in storage seems to occur when certain conditions arise within the tree. The experiments on girdling and defoliating indicate that these conditions may be present in one part of the tree, being restricted to certain branches, while the fruit on the tree as a whole remains fairly sound. The fact that in these experiments sound apples were very often found in lots of fruit from a single tree, though in some cases almost the entire crop would be classed as affected with bad browning, indicates that the conditions that bring it about are even much more localized than the individual tree. The evidence accumulated during the course of these investigations gives strong indication as to what may be the conditions in the tree conducive to browning.

Direct evidence on this question is furnished by the very decisive results of thinning the fruit and girdling branches during the summer of 1919. The trees were bearing a heavy crop, and browning was almost negligible in normal fruit during the following winter storage season. Very considerable browning, however, appeared in the large well-nourished fruit from the girdled branches, whereas even less than the average appeared in fruit from branches from which half the leaves had been stripped.

With these facts in mind, before picking in 1920 and again at the time of picking, careful notes were made concerning the density and condition of the foliage on the trees, the size of the crop, and the size of the fruit. The crop in the orchard was light during the 1920–21 season, so the fruits as a rule were of very large size. Individual yields varied from practically no fruit to 6 or 8 boxes per tree. Since most of the trees under observation were very large, even a crop of 8 boxes was not more than an average yield for a normal year.

The foliage on the different trees varied widely in density and appearance. The size of the fruit varied with the size of the crop and the density and condition of the foliage. When the crop was small and the foliage was in good condition, the fruit was usually of large size.

Upon comparing these records with the percentages of browning that developed during the storage season, it was found that trees with the combination of good, rich foliage and a small crop of large-sized fruit have practically always produced fruit that tended to brown very badly. On the other hand, fruit from trees with a large crop of medium-sized apples has almost invariably developed very little browning. Trees possessing very poor foliage and also bearing a very light crop were often difficult to place so far as browning was concerned. Fruit from such trees usually developed moderate browning.

This relationship of the total crop on the tree to the occurrence of browning may be shown by a study of the trees in the nitrogen plat. Records on the fruit from trees of this plat, together with notes made at the time of picking in 1920, are presented in Table 7.

It is impossible to predict accurately from such data as the notes on tree conditions presented in Table 7 how much internal browning will develop during the storage season. It is of interest, however, that all the trees in the nitrogen plat which produced a high percentage of sound fruit are those producing a fairly large crop of medium-sized fruit. Nos. 133, 134, 137, and 138 were all well loaded for trees of their size. Trees Nos. 46, 132, and 136, fruit from which became particularly badly browned, had very light crops of large-sized fruit and excellent foliage.

TABLE 7.—*Extent of the internal browning of apples grown on the nitrogen plat during the season of 1920.*

Tree.	Remarks.	Yield (boxes).	Comparison of results (per cent).		
			Sound.	Medium and bad browning.	
				Tissue.	Core.
No. 44	Foliage good, tree medium size	5 to 6	14.8	22.2	38.8
No. 45	Foliage medium to poor	4	7.5	49.2	47.5
No. 46	Large tree, foliage good	4 to 5	4.0	77.0	78.0
No. 130	....do	3	8.7	31.3	47.8
No. 131	Large tree, foliage medium	3	4.2	42.5	55.0
No. 132	Large fruit, foliage good	3	0	89.4	91.5
No. 133	Small tree, good foliage	4	43.6	7.4	13.5
No. 134	Medium tree, small fruit	8 to 10	30.9	19.1	21.3
No. 135	Large tree, foliage poor	1	0	47.4	56.6
No. 136	Large tree, foliage good	4	1.8	72.7	90.9
No. 137	Small tree, small fruit	7	44.3	6.1	11.5
No. 138	Very small tree, foliage good	3 to 4	40.7	21.2	8.9
No. 139	Foliage medium, fruit medium size	1½	5.8	25.3	36.8
No. 140	Small tree, foliage good	2	10.5	45.6	37.7

The prevalence of browning during the four years in which these records have been kept also bears out the relationship existing between internal browning and the crop on the trees. During the growing and storage season of 1917–18 the orchards under test in the Pajaro Valley proper had a very heavy crop of fruit, and inspection of many boxes of apples showed practically no browning present. The year following, 1918–19, the crop was very light, many trees yielding only 1 to 3 or 4 boxes, but the fruit was of large size. In that year considerable internal browning developed in storage, and undoubtedly only the fact that storage temperatures were held at 36° F. instead of lower prevented disastrous results. During 1919–20 another heavy crop was produced, and only traces of browning appeared in any of the lots except from branches that had been girdled during the growing season. The season of 1920–21 was another "off" year for the orchard, with small yields of large-sized fruit. Internal browning again was very prevalent in fruit stored at low temperatures, and the commercial crop was probably saved only by holding the fruit at temperatures ranging from 36° to 38° F.

It has often been noted in inspecting fruit for browning that the larger apples have a greater tendency to develop browning than the smaller sizes. It is recognized in the trade also that this tendency holds true. There are, however, many specific exceptions where small fruit will become badly browned and where large fruit, under similar conditions, will remain sound; but the average, particularly in fruit from the same tree, seems to greatly favor small fruit for soundness. This again bears out the apparent condition of browning developing largely in fruit grown under conditions of light crop and good leaf

area. Within a single tree the variation in size of individual fruits produced is undoubtedly due in general to variation in the nutritive supply to the different fruits. Heavily loaded or shaded branches will produce small fruit, while branches with good foliage and bearing very few apples will usually produce large specimens in comparison with the rest of the tree.

RÉSUMÉ OF FACTORS CONDUCIVE TO INTERNAL BROWNING.

There are a number of factors which undoubtedly contribute to bring about conditions in the fruit conducive to internal browning when that fruit is placed in storage. Unfortunately, most of these factors, other than storage temperature, are beyond the control of the fruit grower or handler. A résumé of conditions found to be associated with the tendency of Yellow Newtown apples to brown internally in storage is helpful, however, in giving the conditions toward which the orchardist should strive in order to reduce or eliminate this trouble. It is, perhaps, of greater importance that these data give a basis for a fairly accurate prediction of the probable percentage of browning that will develop in any crop. If conditions are right for the development of browning in the fruit, special precaution should be taken to prevent the storage of that fruit at low temperatures.

Internal browning has been most prone to occur in fruit from the lower portions of the Pajaro Valley, where conditions of low temperature and high humidity during the growing season are coupled with very fertile soil. The sunshine and the temperature and air humidity during the growing season are obviously beyond the control of the orchardist. While internal browning is not unknown in other apple-growing regions, it occurs to such a small extent that it is not of commercial importance. This indicates that apples from the Pajaro Valley differ from those from other sections in the tendency to brown internally in storage only in degree, and it is apparently the peculiar growing conditions in this valley which often produce rather large fruits of coarse texture that are responsible for the widespread tendency to browning.

Even in the Pajaro Valley, however, there are certain seasons in which very little browning develops in the fruit, and in seasons when browning does develop there are certain trees the fruit from which develops very little browning as compared to that from other trees about them. And even from trees most of the fruit of which shows bad browning certain apples will remain entirely sound in cold storage.

All these facts indicate that internal browning is due to some condition within the tree, probably nutritional, which affects the fruit. This condition may be very general, and a large percentage of

browning will develop in fruit from over the district as a whole, or it may be so limited that browning will be practically unknown commercially during certain seasons.

CONCLUSION.

During the four years in which the present investigators have been studying this trouble, it has been found that seasons of very high crop production have been practically free from internal browning. During years when browning was prevalent the fruit from trees producing very heavy crops has been relatively much more nearly free from the trouble than neighboring trees that produced light crops. On a single tree it has been possible, by heavy thinning and girdling of branches, to produce apples that tended to brown badly, while partial defoliation of well-loaded branches resulted in sound fruit. Heavy fertilization with manure tended to increase the percentage of browning, and heavy nitrogen fertilization increased browning markedly in all trees except those bearing a very heavy crop of fruit.

Apparently under the growing conditions of the Pajaro Valley fruit tends to brown internally in storage when light crops of large coarse-textured fruit are produced. It is impossible for the orchardist to control weather conditions, and it is not always possible to obtain a uniformly heavy crop on the trees. Internal browning apparently does not develop seriously, however, if storage temperatures are held at 36° F. or above. It is particularly important that storage conditions be right during years of light crops and large-sized fruit.

SUMMARY.

Certain varieties of apples when placed in cold storage for a long season develop a brown discoloration in the flesh of the fruit which has been designated "internal browning." This trouble is particularly serious in the Yellow Newtown apples grown in the Pajaro Valley district of California, where investigations have been carried on for a number of years.

This trouble is not caused by a parasitic organism but appears to be brought about by certain conditions within the fruit itself.

Apples from the Pajaro Valley have been found to be far more susceptible to this trouble than those from any other section of the country. This district has an extremely cool growing season, coupled with high humidity and fertile soil conditions.

Internal browning develops to a far greater extent in fruit held at 32° than that kept at 36° or 40° F. Its occurrence to an extent sufficient to be important commercially can be largely prevented by storing the Pajaro Valley apples at 36° to 38° F.

There is usually a sharp increase in the percentage of browning in the fruit following its removal from cold storage.

Internal browning develops mainly in those orchards having high soil fertility and located in the California coastal fog belt, where the humidity is high and there is little sunshine.

It has not been possible to produce internal browning in apples or to prevent its appearance by any one of several fertilizer treatments carried out in orchards during a period of four years.

Internal browning of apples varies widely in the fruit from individual trees during any single year, and a given tree does not produce year after year fruit tending to become browned when put in storage. Often a tree will produce sound fruit one year and fruit that becomes badly browned the year following.

Apples of large size, high in sugar and acid content, and from branches girdled during the growing season tended to become browned to a much greater extent than normal fruit from the same tree. Apples from branches partially defoliated showed markedly less browning than fruit from branches with normal foliage.

Internal browning develops mainly in apples from trees growing under the environmental conditions described during seasons when the crop on the tree is very light and the fruit tends to large size and coarse texture. When a heavy crop is produced, little internal browning seems to develop. With a light crop of large-sized apples, holding the fruit at 36° F. or above will prevent serious loss from this trouble in cold-stored Yellow Newtown apples.

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